

# Flicker noise of high-speed p-i-n photodiodes

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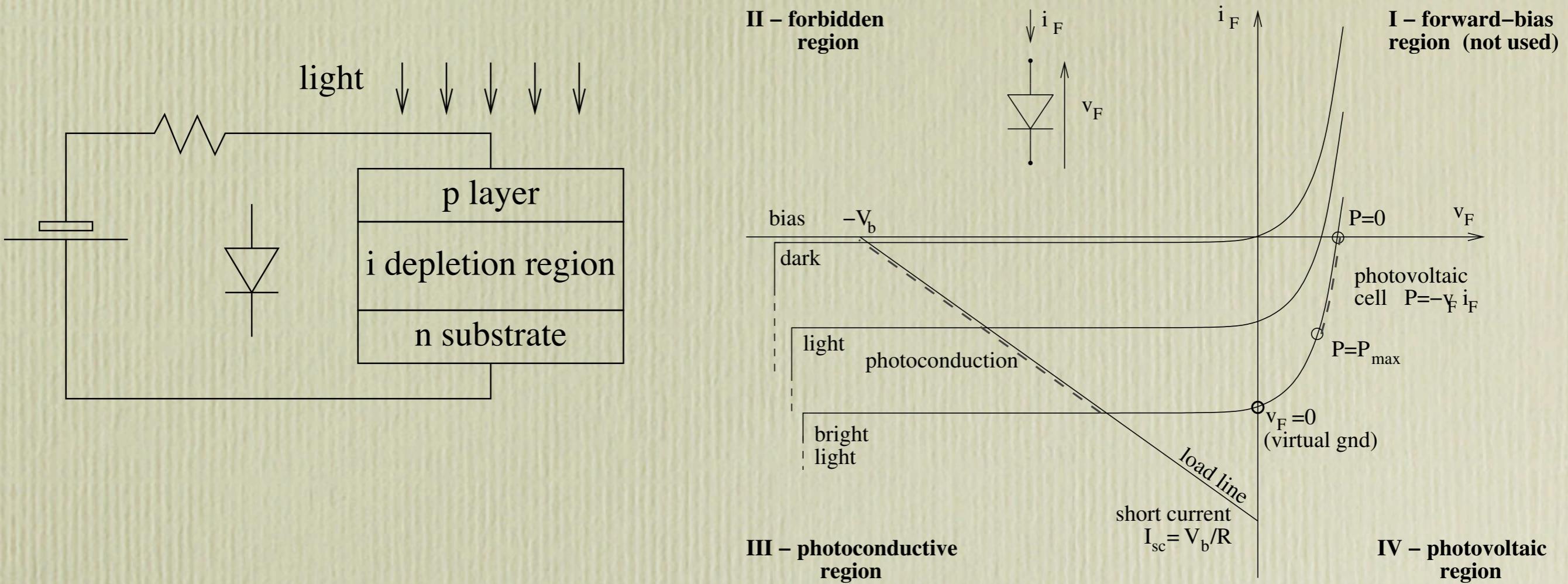
@ OEwaves, Pasadena, CA, USA

## Outline

- introduction
- method
- background noise
- results

Work carried out at the JPL/CALTECH  
under NASA contract, with support from ARL and AOSP/DARPA

# p-i-n InGaAs photodiode



photoconductive region  $\Rightarrow$  lowest C  $\Rightarrow$  high speed

# Signal and noise

microwave-modulated IR

$$P_\lambda(t) = \bar{P}_\lambda [1 + m \cos 2\pi\nu_0 t]$$

microwave photocurrent  
with AM and PM noise

$$i_{\text{ac}}(t) = \rho \bar{P}_\lambda m [1 + \alpha(t)] \cos [\omega_0 t + \phi(t)]$$

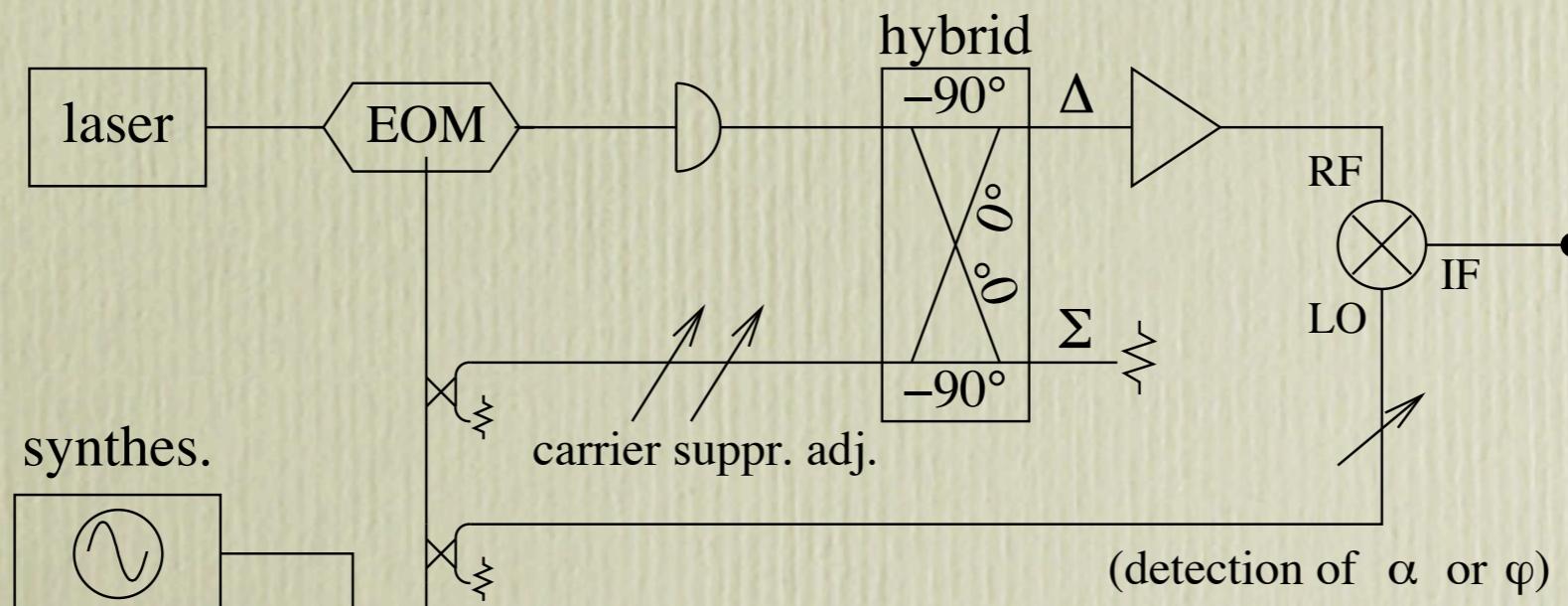
**Virtually no information on AM/PM flicker is available**

## Motivations

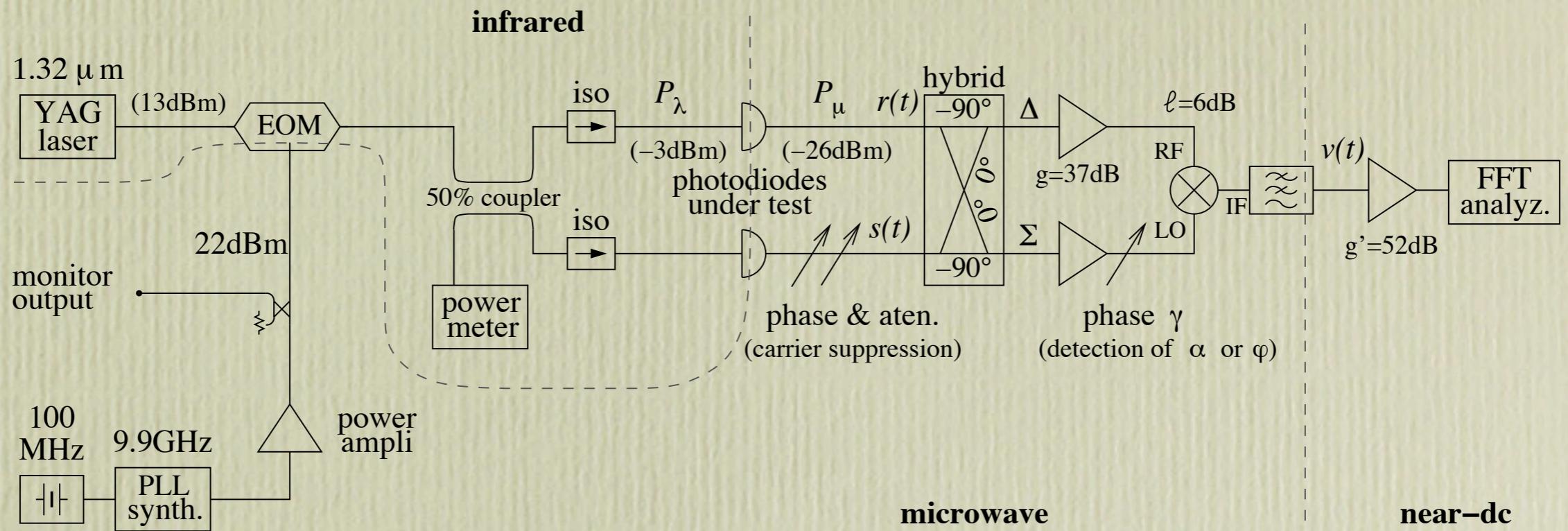
- frequency distribution systems  
deep space network, VLBI, inter-lab link
- laser metrology
- photonic oscillators (Leeson effect)

# Experimental method (I)

- the photodiode output is insufficient to saturate a mixer
- a preliminary survey suggests that the photodiode phase flickering is lower than that of a microwave amplifier  
(typical amplifier flicker  $-105 \text{ dBrad}^2/\text{Hz}$  at 1 Hz)
- we choose some photodiodes similar to one another, with a max speed of some 12-15 GHz  
(Discovery Semiconductors, Fermionics, Lasertron)
- a single-photodiode interferometric (bridge) scheme can't work because the equilibrium condition is difficult



# Experimental method (2)



- **interferometric (bridge) scheme**
  - # low phase noise, limited by the noise figure of the  $\Delta$  amplifier
  - # carrier rejection in  $\Delta$  => the  $\Delta$  amplifier does not flicker
  - # rejection of the source noise

Rev. Sci. Instr. **73** 6 p. 2445 (2002), and arXiv:physics/0503015

- the noise of the  $\Sigma$  amplifier is not detected  
Electron. Lett. **39** 19 p. 1389 (2003)

# Background noise (I)

- well understood:

- phase-to-voltage gain [V/rad]

$$k_d = \sqrt{\frac{g P_\mu R_0}{\ell}} - \begin{bmatrix} \text{dissip.} \\ \text{loss} \end{bmatrix}$$

- thermal noise

$$\begin{aligned} S_{\phi t} &= \frac{2FkT_0}{P_\mu} + \begin{bmatrix} \text{dissip.} \\ \text{loss} \end{bmatrix} \\ &= \frac{2FkT_0}{R_0 \rho^2 \bar{P}_\lambda^2 m^2} + \begin{bmatrix} \text{dissip.} \\ \text{loss} \end{bmatrix} \end{aligned}$$

- shot noise

$$S_{\phi s} = \frac{4q}{\rho m^2 \bar{P}_\lambda}$$

- experimentally determined or up-bounded:

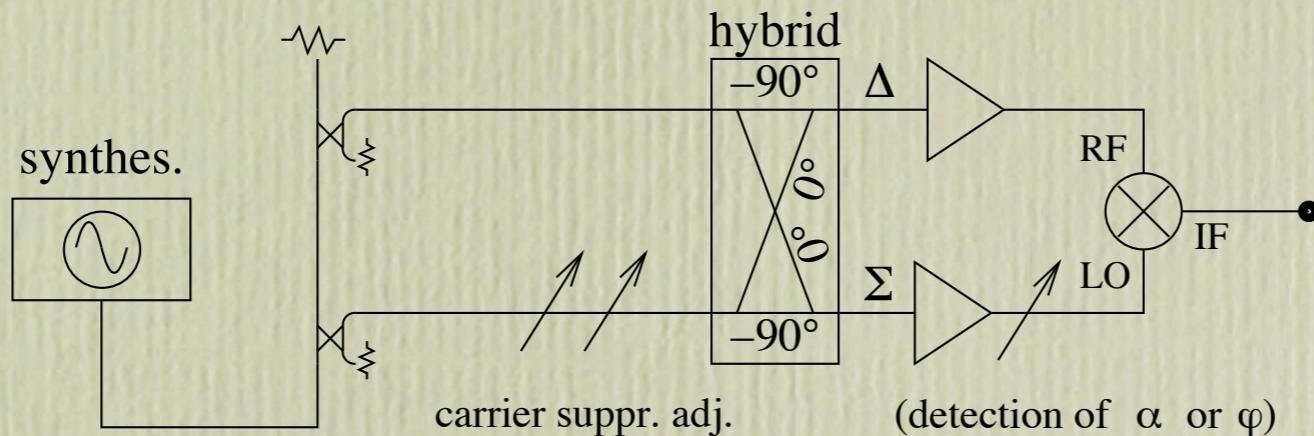
- contamination from AM noise (RIN)
- flicker noise

$g$	power gain ( $\Delta$ ampli)
$P_\mu$	microw. pow.
$R_0$	charact. resist. ( $50 \Omega$ )
$\ell$	ssb mixer loss
$F$	noise figure ( $\Delta$ ampli)
$kT_0$	thermal energy ( $4 \times 10^{-21} \text{ J}$ )
$q$	electron charge ( $1.6 \times 10^{-19} \text{ C}$ )
$\rho$	responsivity [A/W]
$m$	modulation index
$P_\lambda$	optical power

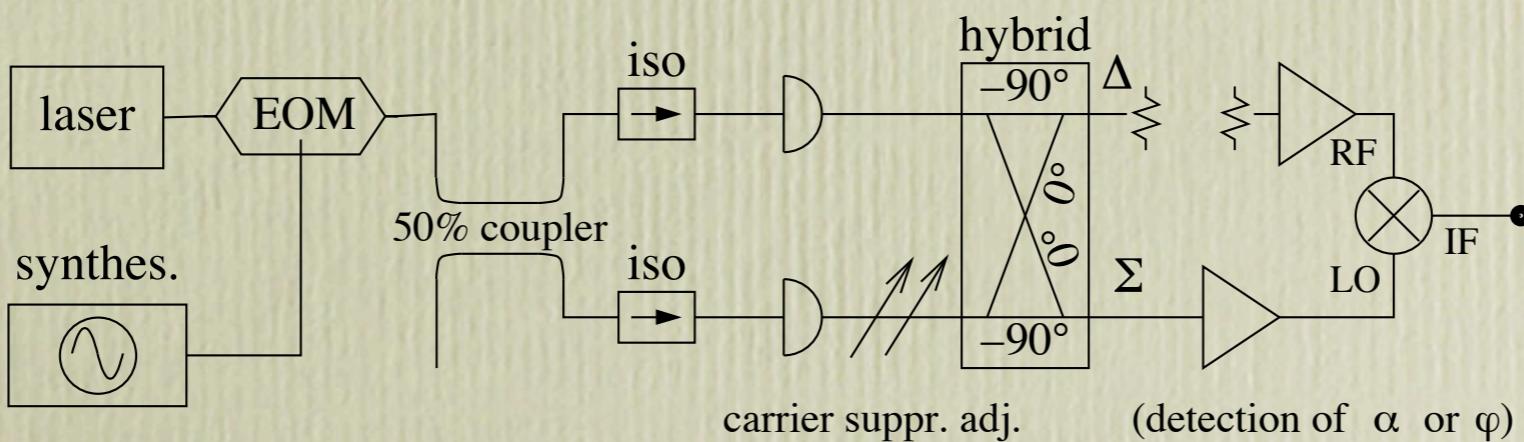
# Background noise (2)

low optical power => thermal noise >> shot noise

## I. replace the detectors with microwave signals



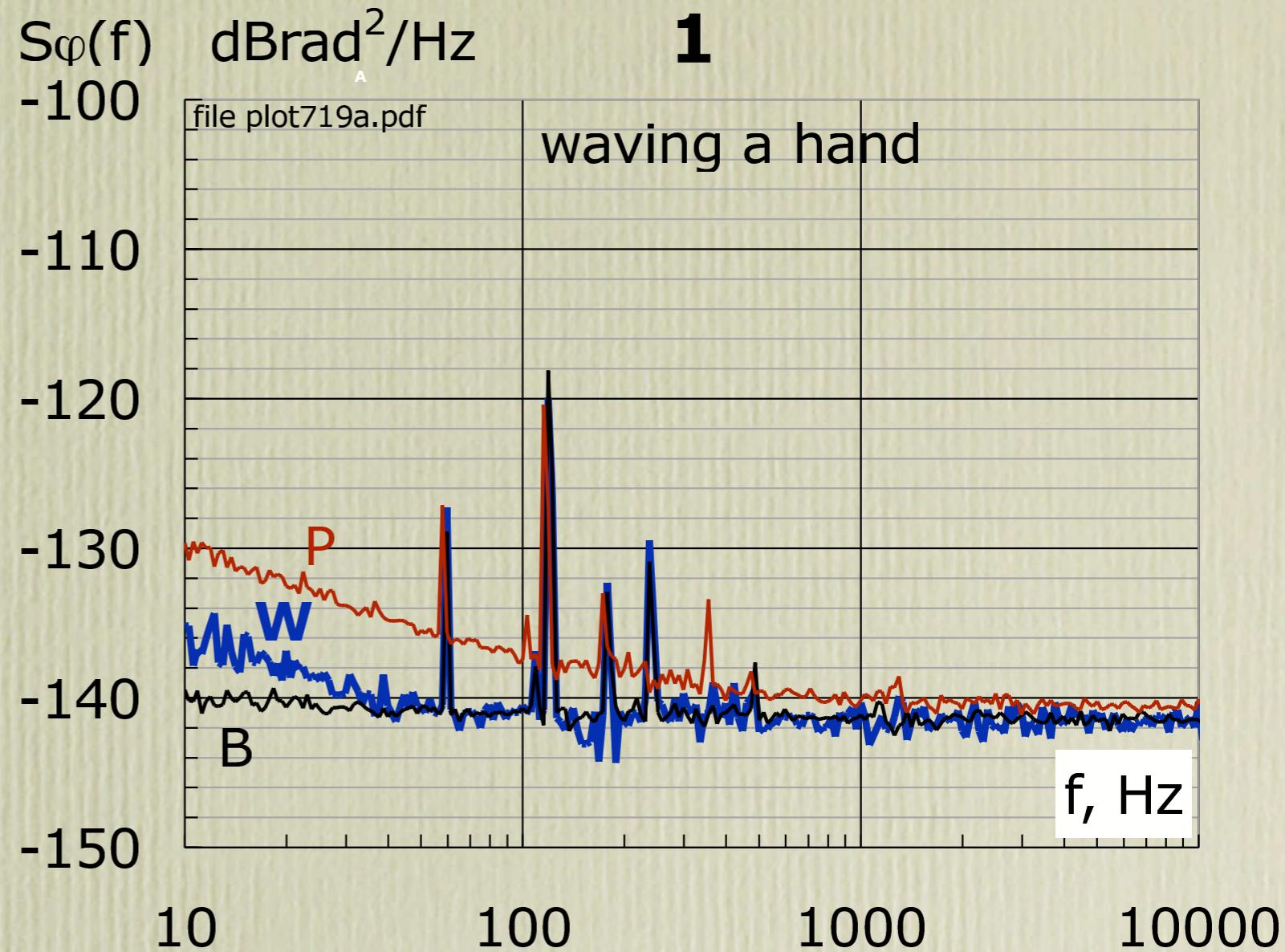
## 2. terminate the input of the delta amplifier



... and take the worst case

# Technical difficulties (I): crosstalk

- high EOM driving power (22 dBm)
- low photodiode output power (-26 dBm)
- finite isolation (100-120 dB?)
- even small fluctuations of the environment induce noise as a consequence of the fluctuating crosstalk
- work nighttime, when nobody is around

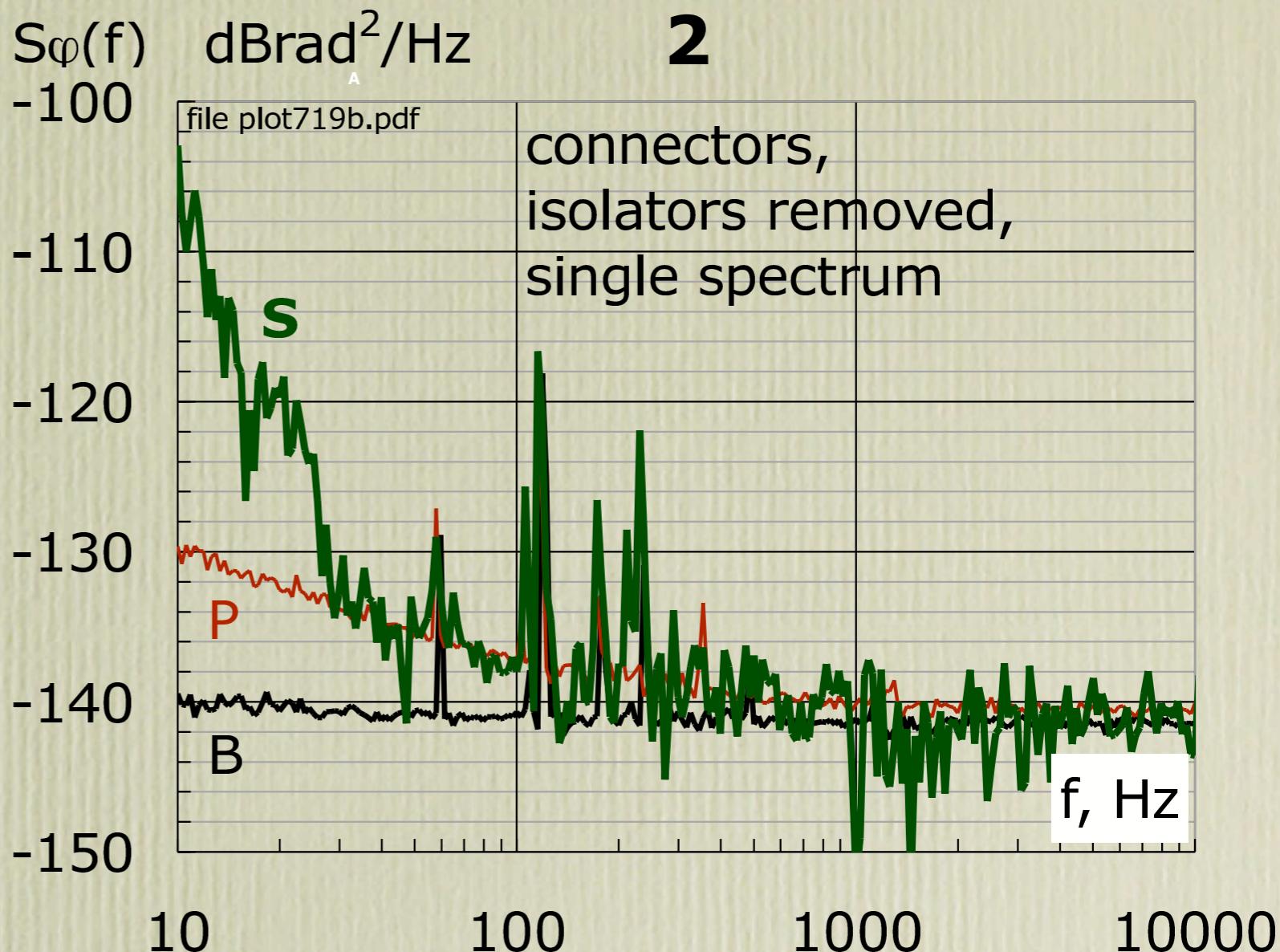


**W:** **waving a hand 0.2 m/s,  
3 m far from the system**

B: background noise  
P: photodiode noise

# Technical difficulties (2): reflections

- back reflections cause the spectrum to be polluted
- flares appear at random in some spectra, as shown
- unexplained physical mechanism



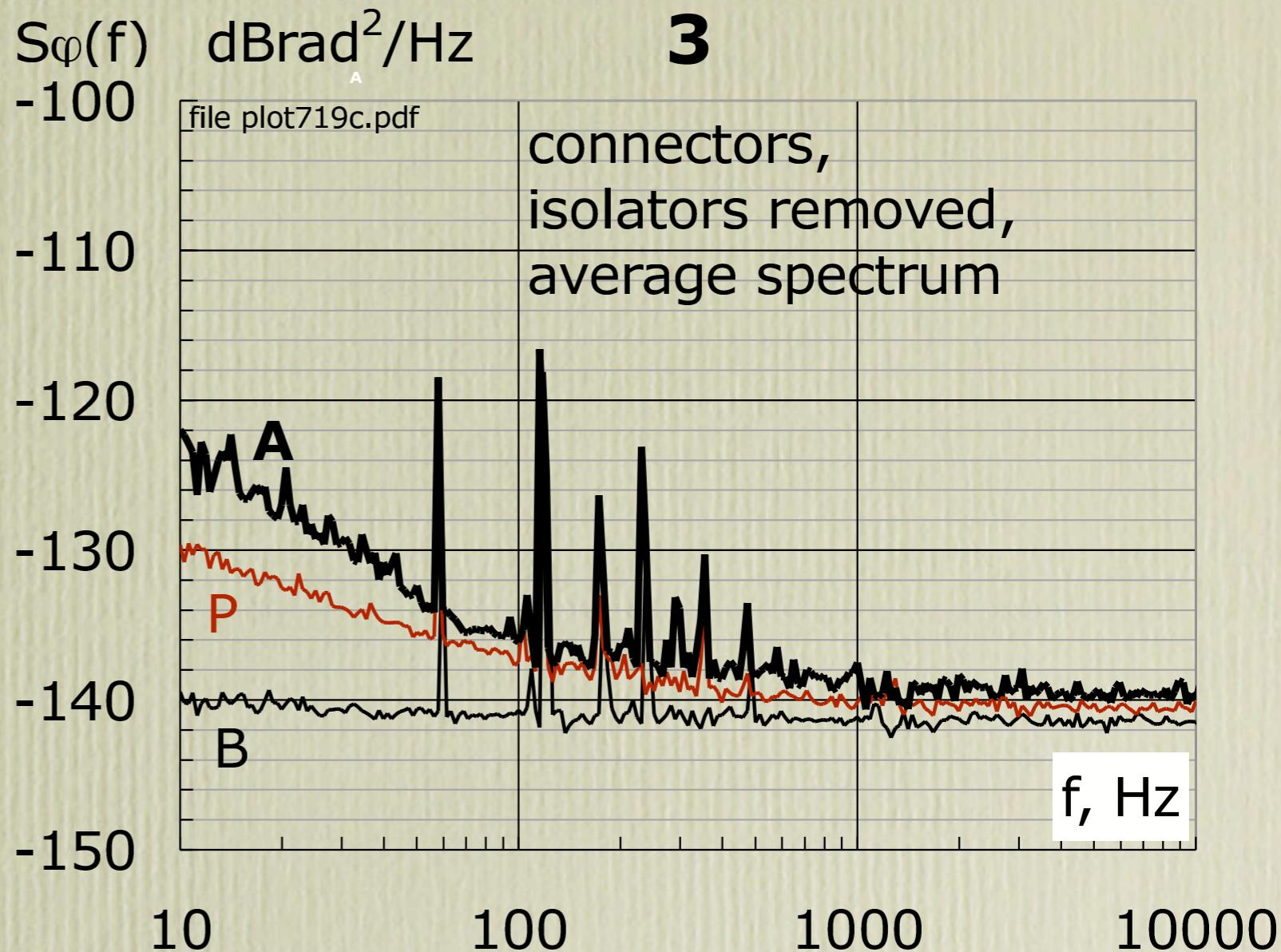
**S: example of single spectrum, with optical connectors and no isolators**

B: background noise

P: photodiode noise

# Technical difficulties (3): reflections

- back reflections causes spectra to be polluted at random
- the average spectrum is smooth
- wrong slope
- it is difficult to identify and to discard polluted spectra



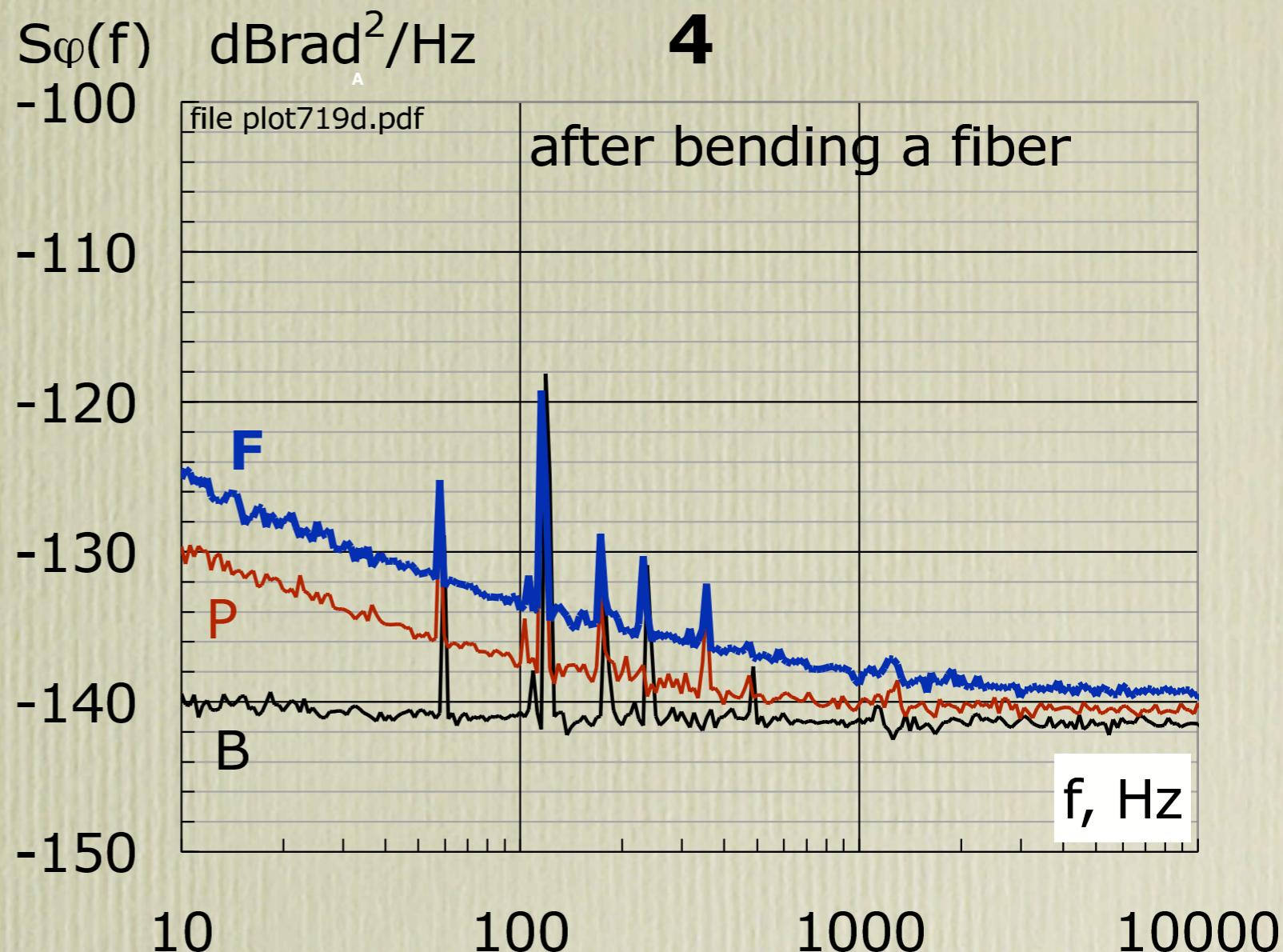
**A:average spectrum, with optical connectors and no isolators**

B: background noise

P: photodiode noise

# Technical difficulties (4): fibers

- the path of the optical fibers affects the internal stresses, and in turn the reflections
- unpredictable effect on noise, which is *not* the photodiode noise
- trimming the system takes patience

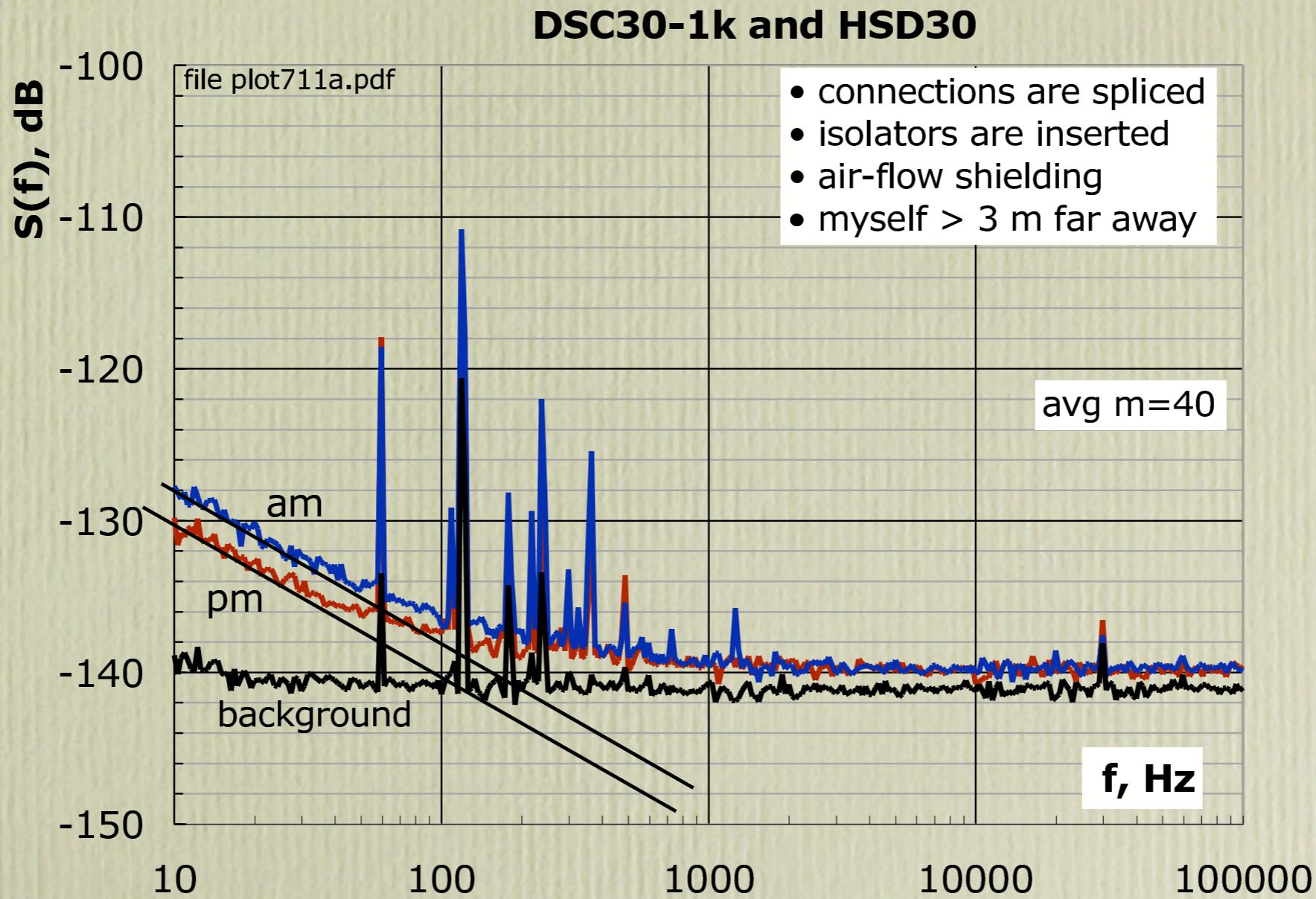


**F: after bending a fiber, 1/f noise can increase unpredictably**

B: background noise

P: photodiode noise

# Example of photodiode noise



... after patient adjustement

# Some results

all the pair of two different photodiodes are compared

photodiode	$S_\alpha(1\text{ Hz})$		$S_\varphi(1\text{ Hz})$	
	estimate	uncertainty	estimate	uncertainty
HSD30	-122.7	-7.1 +3.4	-127.6	-8.6 +3.6
DSC30-1K	-119.8	-3.1 +2.4	-120.8	-1.8 +1.7
QDMH3	-114.3	-1.5 +1.4	-120.2	-1.7 +1.6
unit	dB/Hz	dB	dBrad <sup>2</sup> /Hz	dB

## estimated uncertainty

0.5 dB random, affects the differences  
(amplified by the three-corner method)

1 dB systematic, affects all values in the same way  
(non amplified by the three-corner method)

# Conclusions

- the photodetectors we measured are similar in AM and PM I/f noise
- the I/f noise is about  $-120 \text{ dB}[\text{rad}^2]/\text{Hz}$
- other effects are easily mistaken for the photodetector I/f noise
- environment and packaging deserve attention in order to take the full benefit from the low noise of the junction